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PAIRED-PULSE DECODERS
PROVIDING
ECHO SUPPRESSION

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**PAIRED-PULSE DECODERS
PROVIDING
ECHO SUPPRESSION**

by

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April 1947

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ABSTRACT

The technique of diode mixing of signals has produced new decoder circuits for IFF interrogation systems which provide echo and spike suppression and which are more economical of tubes than previous circuits. The three new circuits discussed require equality of pulse amplitude as well as proper pulse spacing for decoding. They are free from the recovery-time defect and the pulse (railings) jamming vulnerability of RC integrating circuits, and they eliminate the spurious outputs which result from coincidence of pulse edges.

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1. CRG Report No. 17 of 6 January 1945 by G. B. Parkinson: The Development of Decoders for the Mark V IFF System.
2. CRG Report No. 92 of 9 October 1945 by R. H. Brown: Mark V UNB/IFF System Design.
3. NRL ltr. C-S67/89Mk 5(1354HMS), C-1350-3/47.
4. CRG Report No. 87 of 26 September 1945 by J. R. Parsons: Design and Construction of Continuously Wound Delay Lines.
5. Division 14, NDRC Report No. 565 of October 1945 by J. H. Scaff and H. C. Theuerer: Final Report on Preparation of High Back Voltage Germanium Rectifiers.
6. CRG Technical Memorandum No. 92 of 15 October 1945.

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PAIRED-PULSE DECODERS PROVIDING ECHO SUPPRESSION

INTRODUCTION

1. The reliable operation of IFF systems employing multiple-pulse interrogation coding requires that the decoder recognize and initiate responses only to valid interrogations, even in the presence of interference. In earlier systems (for example, the Mark V system), interrogation has consisted of two pulses of approximately equal amplitude wherein the separation of the leading edges of the pulses constituted the code.
2. It has been the practice to examine only the spacing of a pulse sequence, and to initiate a reply to a correctly spaced pair although the pulses differ greatly in amplitude. Such a pair does not constitute a valid interrogation, and we shall examine subsequently how such combinations arise and in what manner they cause confusion.
3. In addition to the direct path of the signal from the interrogator to the transponder, there are generally other propagation paths involving one or more reflections. From the information contained in CRG Report No. 91, "Flight Test Group Report" by Squadron Leader A. H. Ratcliffe, it appears that, in air-to-air interrogation, most ground returns are 20 db down on the main signal with a maximum response of the order of 12 db down. Sea returns are much stronger - 40% are more than 18 db down on the main signal, 55% are 9 db down, and 85% are less than the direct signal. In air-to-ground interrogation, echoes were observed usually only at close range and on the average were about 20 db down; no mention was made of sea-to-air interrogation.
4. A reflected interrogation can, if suitably delayed, cause a transponder to fire on the wrong code. For example, a transponder which is supposed to reply to an IR interrogating with a five-microsecond code might be triggered by a reflected signal at three microseconds. Such false triggering may cause transponder overloading which will result in high count down and poor response to the proper interrogation. Similarly, if a transponder is supposed to accept both interrogation codes, the reflected signals may cause premature triggering, which will result in instability in the range indication by the amount which corresponds to the difference in code spacing. Or, if reply coding be employed, premature triggering of the transponder will result in an incorrect reply unless all the reply codes can be simultaneously observed.
5. When a radar is employed in conjunction with the IFF, the possibility exists that a radar pulse occurring prior to the first IR pulse will upset the coding system. However, interference from this source may be minimized by the use of filters to eliminate the radar frequencies.*

* A more thorough description of these effects and other difficulties encountered in the Mark V system design is presented in CRG Report No. 92 by R. Hanbury Brown.

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HAZELTINE ECHO-SUPPRESSION CIRCUIT

6. Since all previous solutions to the echo-suppression problem have been similar in principle, the discussion of a single case will suffice. A typical example is the "Hazel-tine Bowl Circuit", shown in Figure 1.

7. The signal from the receiver's video amplifier charges a capacitor in the grid of VT 2A through Diode 1. The common cathode arrangement holds VT 2B to a bias proportional to the input signal for a time following the first pulse as determined by the time constant of the grid circuit of VT 2A, thereby creating a bias bowl which will suppress succeeding signals of sufficiently low amplitude. The signal is delayed by $0.25 \mu s$ before application to the VT 2B grid so that the bowl is fully formed; that is, the capacitor in the grid of VT 2A is fully charged before any signal appears on the VT 2B grid. If the signal applied to VT 2B were not delayed, it would load the driving stage.

8. The performance of the circuit is shown in the following table:

Spacing of Echo from Initial Pulse in μs	Amplitude of Initial Pulse In volts	Amplitude of Echo below that of Initial Pulse for complete suppression in db
3	1	6.8
3	10	6.0
8	1	10
8	10	14

9. Signals from video pulse generators were used to obtain these results. The pulses were about $1.4 \mu s$ wide, and had rise and fall times of approximately $0.2 \mu s$.

10. These data seem to indicate that such an echo-suppression circuit would be adequate in most cases. There are, however, certain objectionable features which will be pointed out later. One of the most important objections is that the circuit increases the susceptibility of the set to railings jamming. Research and development work was begun, therefore, to determine both to what extent it is possible to discriminate against echoes and the manner in which this can best be accomplished.

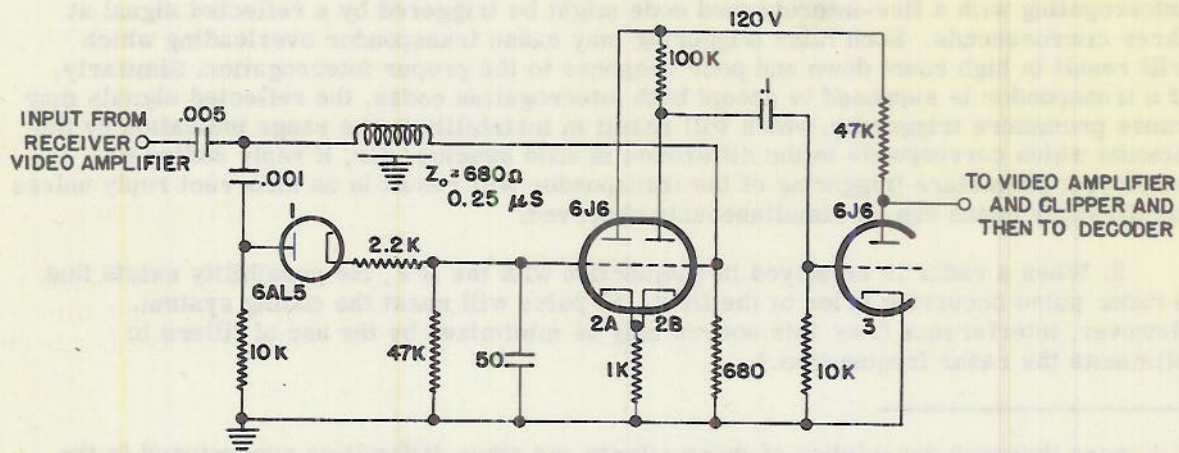


Figure 1. Hazeltine "Bowl" Circuit

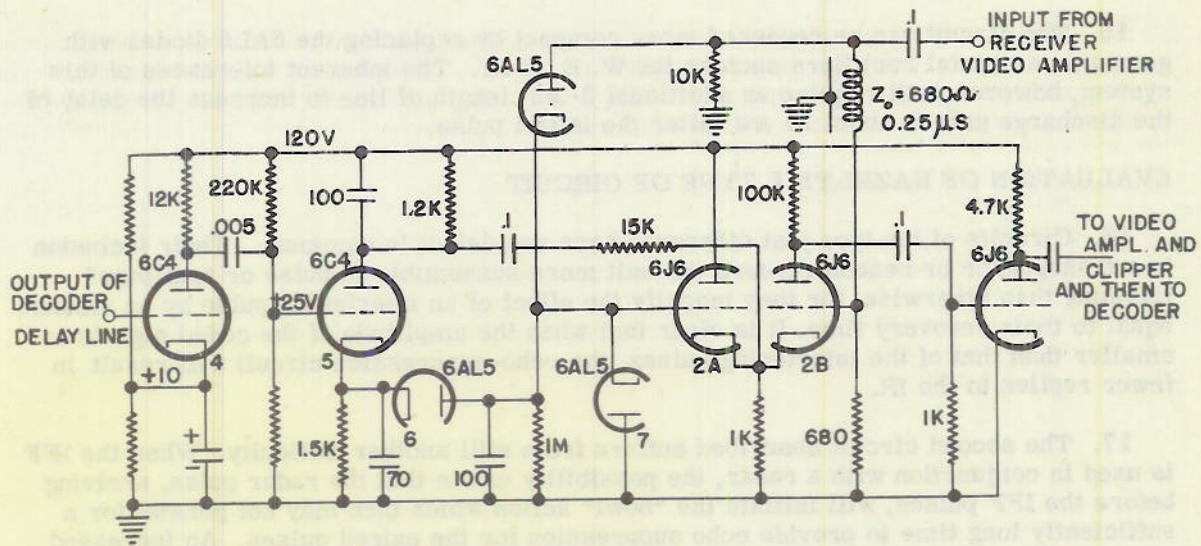


Figure 2. Modified Hazeltine Circuit

MODIFIED HAZELTINE ECHO-SUPPRESSION CIRCUIT

11. Initial experiments were directed toward improving the discrimination of the Hazeltine circuit. The improved circuit, illustrated in Figure 2, discriminates against echoes by means of the long-time-constant circuit in the grid of VT 2A. This circuit may be completely discharged in one microsecond as follows.

12. A one- μ s positive pulse delayed by 8 μ s is obtained from the output of the decoder delay line (8 μ s corresponds to the maximum pulse spacing used), and is used here as the gate which allows the grid condenser of VT 2A to discharge. The polarity of the pulse is reversed by VT 4, and a negative pulse of sufficient amplitude to cut off completely VT 5 is applied to its grid. The cathode of VT 5 is normally at +25 v, which serves to bias off Diode 6. However, when VT 5 is cut off, its cathode falls to ground potential and the 100- μ f capacitor discharges through the diode VT 6 and the 1.5-K resistor in the cathode of VT 5.

13. The plate-cathode capacity of Diode 6 along with the associated wiring capacity allows a negative signal to feed through to the grid of VT 2A whenever the discharge pulse is applied to VT 5. A positive pulse of the correct amplitude is applied to the cathode of VT 2 to compensate for the negative voltage appearing upon the grid of VT 2A. This voltage is obtained from the plate circuit of VT 5 when it is cut off. Small condensers shunt the cathode and plate load of VT 5 to eliminate spikes which would otherwise be present. Diode 7 prevents the 100- μ f capacitor from acquiring a negative charge.

14. The performance of the circuit is shown below:

Spacing of Echo from Initial Pulse in μ s	Amplitude of Initial Pulse in volts	Amplitude of echo below that of Initial Pulse for complete suppression in db
3	1	6.0
3	10	1.8
8	1	6.8
8	10	2.9

15. The circuit can be rendered more compact by replacing the 6AL5 diodes with germanium crystal rectifiers such as the W. E. 400A. The inherent tolerances of this system, however, will require an additional 2- μ s length of line to increase the delay of the discharge gate to about 10 μ s after the initial pulse.

EVALUATION OF HAZELTINE TYPE OF CIRCUIT

16. Circuits of the type just discussed have one defect in common. Their inclusion in a transponder or beacon renders the unit more susceptible to pulse or "railings" jamming than otherwise, for they magnify the effect of an interfering pulse by an amount equal to their recovery time. It is clear that when the amplitude of the coded signals is smaller than that of the interfering pulses, the echo-suppression circuit will result in fewer replies to the IR.

17. The second circuit described suffers from still another difficulty. When the IFF is used in conjunction with a radar, the possibility exists that the radar pulse, arriving before the IFF pulses, will initiate the "bowl" action which then may not persist for a sufficiently long time to provide echo suppression for the paired pulses. An increased recovery time of the circuit will remedy this defect, but will conflict with the requirement that the recovery time be as short as possible.

18. It is evident that if the function of echo suppression is to be accomplished without introducing undesirable recovery time into the operation of the transponder, a method which is not based upon the properties of an RC circuit must be employed. New techniques were developed for video-pulse decoding based upon a decoder which can select the signals comprising the code by the application of two criteria: pulse spacing and pulse amplitude. As a by-product of the new technique, "spike" suppression is included as an integral part of the decoder.† Such a decoder will automatically provide echo suppression.

DECODER EMPLOYING SPACING AND AMPLITUDE DISCRIMINATION

19. The decoders to be described are all of a type which is either similar to that employed in the Mark V beacons, or which can easily be adapted for beacon use. The design constants have been determined by the Mark V IFF system, since equipments were readily available for experimental work. If a different choice of pulse lengths and spacings were chosen, the constants would have to be suitably altered. An additional circuit is required in the case of the Mark V airborne transponder to enable it to transmit the special PI reply when so interrogated.

20. In order for the decoder to provide pulse-amplitude discrimination, it is required that the receiver output be linear (or vary in some other regular manner) over as great a range of signal strengths as possible. For example, if the receiver is linear over a 40 db range and the minimum signal at the detector output is 0.5 volt, the maximum output before the receiver saturates is 50 volts. Or, if the system has a maximum free-space range of 500 miles, saturation of the transponder receiver will not occur until it is within 5 miles of the IR. These figures indicate the range over which pulse-

† When a transponder is tuned to a channel different from that of the IR, sideband radiations from the interrogator produce short pulses ("spikes") corresponding to the beginning and end of each interrogation pulse. Unless precautions are taken these spikes can be decoded and produce triggering of the transponder. See CRG Report No. 92 by R. H. Brown, pages 83 and 84.

24. The same analysis holds for the VT 3 comparator, except that the grid of 3A receives the delayed signals. When the undelayed signal is greater in amplitude than the delayed signal, a negative pulse will appear at the plate of VT 3.

25. The outputs of the comparators are coupled to the control grid of the 6AS6, VT 4, by means of diodes, so that only negative signals may appear at this point. The diodes serve also to isolate the comparators. Isolation is necessary, since the output of one comparator is negative when the output of the other is positive and, therefore, the discrimination of the comparator would be adversely affected if its output were reduced as a result of the other comparator.

26. Figure 4 will assist in clarifying the functioning of the comparators. An initial pulse of amplitude C will cause a negative output of comparator VT 2 whenever the amplitude of the second pulse is less than A. Likewise, whenever the amplitude of the second pulse is greater than B, the output of the comparator VT 3 will be negative. Thus, the condition that a negative pulse will not appear at the control grid of VT 4 for any correctly spaced pair of pulses is that the ratio of their amplitudes fall within the predetermined limits A and B.

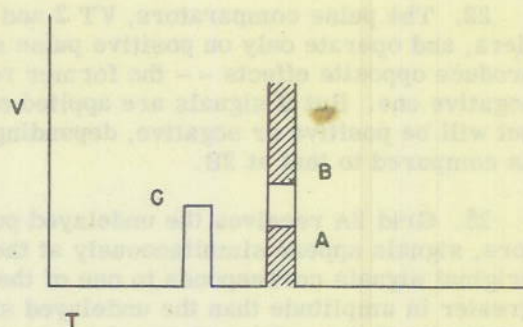


Figure 4. Operation of comparators of Figure 3 circuit

27. It is clear that single pulses will always produce a negative pulse at the control grid of VT 4, for, if only an undelayed pulse is present, the comparator VT 3 will produce a negative output, and, if only a delayed pulse is present, the comparator VT 2 will produce a negative output.

28. The decoder output, consisting of negative pulses, is obtained from the plate circuit of VT 4, a 6AS6 operated Class A. The flow of current through VT 4 is modulated by two signals -- undelayed signals on its suppressor grid, and signals from the comparators on its control grid. There will be an increase in the flow of plate current through VT 4 (the condition for decoder output) if the appearance of a positive pulse at the suppressor grid is not nullified by a negative pulse at the control grid. We have seen that the conditions under which no negative pulse will appear at the control grid of VT 5 are that the pulses be correctly spaced, and that the ratio of their amplitudes fall within specified limits.

PULSE EDGE EFFECTS

29. For the sake of simplicity, "edge" effects were ignored in discussing the technique of pulse-amplitude comparison. We must now take them into consideration.

30. On Figure 5 (A) is shown the case of perfect coincidence between a delayed and an undelayed pulse. Although the pulses differ greatly in peak amplitude, during the time intervals t_1 and t_2 their amplitudes are nearly identical. Therefore, during the times t_1 and t_2 the conditions for decoding are satisfied, and narrow pulses appear in the decoder output corresponding to the times t_1 and t_2 .

31. Similarly, on Figure 5 (B) the requirements for decoding are satisfied over the region t_3 and a narrow pulse will appear in the output of the decoder.

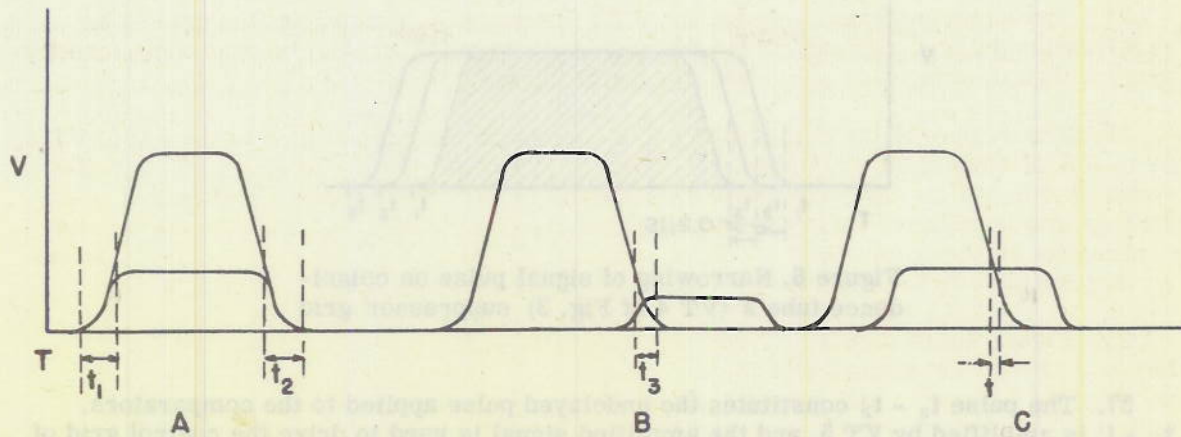


Figure 5. Pulse-edge effects

32. The case shown in Figure 5 (C) is relatively unimportant, since the overlap period is so short that the decoder output amplifier, VT 4, does not have sufficient bandwidth to show an appreciable output.

33. A good estimate of the overlap period can be made by considering the rise and fall times of the pulses involved. The signals used to examine the operation of the circuit were supplied by thyratron pulse generators capable of producing flat-topped, one- μ s pulses, with rise and fall times of about 0.15μ s, variable in amplitude from 0 - 70 volts, into a 200-ohm load. One would expect, therefore, to observe "false" decoder outputs with a maximum width of about 0.2μ s. This figure is in excellent agreement with the actual observations.

34. The diagrams shown in Figure 5 are incorrect inasmuch as the pulses are depicted as having similar forms. Since one is an undelayed pulse and the other a delayed pulse, they must differ in shape by the distortion introduced by the delay line. This distortion will be a function of the characteristics of the line and the delay time. However, in the case where the pulses are different, the overlap period is determined by the pulse with the fastest rise and fall times and so will be determined by the form of the undelayed pulse. This result is identical with that of the previously discussed case.

35. An early solution to the "edge" effect problem is shown in Figure 3 and involves two $0.2\text{-}\mu$ s sections of delay line and vacuum tubes 5, 6, 7 and 8. If VT 4 could be prevented from conducting during the time of rise and time of fall of the signal pulse, no "false" narrow pulses would exist in the output of the decoder. These false pulses occur because VT 4 is prepared to conduct as soon as the undelayed pulses appear upon its suppressor grid, and because the information derived from comparators is not correct during the rise and fall times of the signals.

36. By means of two $0.2\text{-}\mu$ s sections of video delay line, a new signal is formed from the undelayed pulse which is narrower by an amount equal to the rise and fall time of the pulse, and the peak of which is in exact time correspondence with the undelayed pulse. The diagram in Figure 6 shows the time relationship of the undelayed signal at the positions designated on Figure 3 as -0.2μ s, 0 , 0.2μ s.

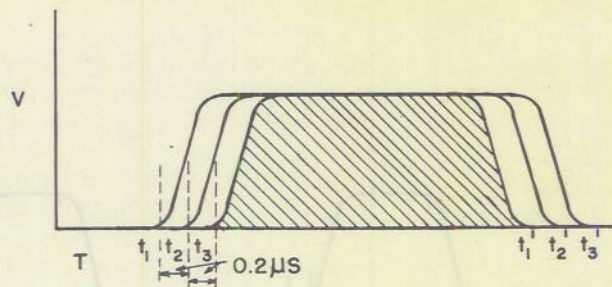


Figure 6. Narrowing of signal pulse on coincidence tube's (VT 4 of Fig. 3) suppressor grid

37. The pulse $t_2 - t_2'$ constitutes the undelayed pulse applied to the comparators. $t_1 - t_1'$ is amplified by VT 5, and the amplified signal is used to drive the control grid of VT 7 which is a 6AS6 biased beyond the cutoff potential on both the control and suppressor grids. $t_3 - t_3'$ is amplified by VT 6, which drives the suppressor grid of VT 7. But VT 7 conducts only when signals appear simultaneously on both grids. This condition is satisfied only during the interval, $t_3 - t_1$, the shaded region of the diagram. Thus, the output of VT 7 consists of a negative pulse of duration $t_3 - t_1'$ which corresponds in time to the "middle" of the $t_2 - t_2'$ pulse. This pulse is reversed in polarity by VT 8 and applied as signal to the suppressor grid of VT 4.

38. When the signals on the suppressor grid of VT 4 are narrowed in the manner specified, spurious decoder outputs are eliminated. Also, since pulses less than $0.4 \mu s$ wide can produce no VT 7 output and, therefore, no VT 4 signal, the circuit affords spike suppression.

DIODE MIXING OF DELAYED PULSES

39. There is another important difference between this decoder and the decoders which are presently employed in the Mark V equipments. The present Mark V decoders employ a separate 6AS6 for each of the delay line taps designated $3 \mu s$, $5 \mu s$, and $8 \mu s$ (corresponding to the three interrogation codes) on Figure 3. A great saving in tubes, with the attendant economies of power and space, has been effected by the use of germanium crystal rectifiers, (such as the W.E. 400A) for introducing the signals at the three taps into a common circuit element, so that only a single coincidence tube need be used.

40. In order that the comparators provide correct information on each of the codes, it is necessary for the delayed signals to be of equal amplitude regardless of the delay. This is accomplished by means of the series resistors in the diode tap circuits. All the delayed signals are reduced to the level of those with the greatest delay (the $8-\mu s$ code) by the series resistors in the diode tap circuits, and thus a single comparator provides the same discrimination for any code.

41. However, this saving is not affected without some sacrifice in circuit performance. Consider the train of pulses at the decoder input shown in Figure 7. Pulses 1 and 3 constitute a valid interrogation. Pulse 2 is an interfering pulse much larger in amplitude than 1 or 3. At the same time that pulse 1 appears at the $5-\mu s$ tap, pulse 2 appears at the $3-\mu s$ tap, and, as a result of mixing the two pulses, the large interfering pulse swamps out pulse 1. When the comparators compare pulses 1 and 3, the presence of pulse 2 will cause them to indicate that they are of unequal amplitude and should not be decoded.

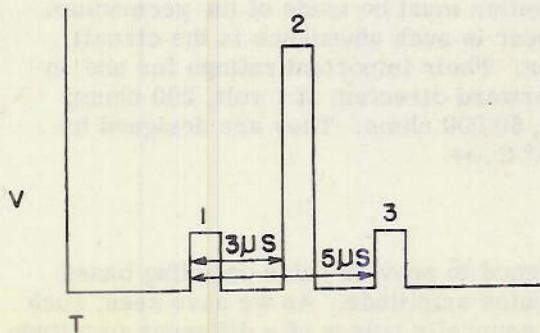


Figure 7. Effect of diode mixing of delayed pulses

tortion of the pulses by circuit and tube capacities, the common load resistor cannot exceed, by much, 5000 ohms. But to prevent a serious reflection from occurring at a delay line tap, the load impedance should be large as compared to the characteristic impedance of the line. The coefficient of reflection is given by

$$K = \frac{R - Z}{R + Z}$$

where Z equals the characteristic impedance of the line, and R is the terminating impedance. For $Z = 2000$ ohms and a load resistor of 5000 ohms, at a tap, $R = 1400$ ohms and $K = -18\%$. This means that a pulse of opposite polarity and 18% of the initial pulse in amplitude will be reflected from the taps.

44. The video delay line itself is the cause of another difficulty. The line used is of the continuously wound, single-sided variety, consisting of a universal progressive winding over a cylindrical plastic former which is silver plated and slotted. † An assemblage of the correct number of these rods for the required delay constitutes the line. In any such assemblage, especially where compactness is required, a length of line can be found in close proximity to another length where the two lengths correspond to different delays. The rods are linked together magnetically and the energy not only travels down the line in the normal manner, but some energy is also transferred to adjacent sections. This gives rise to a lot of wiggles (small pulses) before and after the delayed signals. Although these wiggles are of the order of 20 db down on the delayed pulses, they have sufficient amplitude to act as signals when the pulses are sufficiently strong. It is possible for a single intense pulse which generates these wiggles, in conjunction with a small pulse of the same order of amplitude as the wiggles, to be decoded.

45. The design of a better delay line will do much to overcome the difficulties caused by wiggles and mismatch at the delay-line taps. The amplitude of the wiggles can be reduced by a more careful assembly of the line. The use of a lower impedance delay line will reduce the reflection coefficient at the taps (a 500-ohm line would reduce it to -5%).

46. The problem of delay-line design is being investigated at the present time by another group. Definite information will be available presently, and will indicate both the plausibility and practicability of a line which will adequately meet the requirements of this decoder.

† A good description of this type of delay line, embracing both design and construction aspects, is given in CRG Report No. 87 by J. R. Parsons.

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47. While discussing decoder components, mention must be made of the germanium crystal diodes (WE D172925, WE 400A) which appear in such abundance in the circuit. They approximate in size a $\frac{1}{2}$ -watt carbon resistor. Their important ratings for use in pulse circuits are: maximum impedance in the forward direction at 1 volt, 200 ohms; minimum impedance in the back direction at 50 v, 60,000 ohms. They are designed to operate over a temperature range of -50° C to 90° C. **

EVALUATION OF FIGURE 3 DECODER

48. This decoder (Figure 3) is primarily designed to provide pulse decoding based upon two criteria: pulse spacing and equality of pulse amplitude. As we have seen, such a decoder will reject echoes, because echoes are generally pulses of a different amplitude than the direct signals. The circuit will also discriminate against extremely narrow pulses (less than $0.4 \mu s$), and hence will provide spike suppression.

49. To provide such "bi-critical" decoding, free from ambiguity, it is necessary to introduce a circuit which will eliminate "edge" effects. These "edge" effects cause the production of narrow pulses, or spikes. However, a spike-suppression circuit following the decoder, similar to that presently employed in the Mark V transpondors, †† would provide the necessary protection. The decoder could then be simplified by the elimination of the two $0.2-\mu s$ sections of line and VT 5, 6, 7 and 8.

50. In tests employing signals derived from pulse generators, the circuit of Figure 3 provided unambiguous bi-critical decoding. It was not capable of operating over a 40 db range of signals because of the insensitivity of the amplifiers VT 5 and 6 employed in the edge-effect suppression circuit.

51. Further work on this circuit ceased when it became apparent that other techniques would provide the required type of operation with a simpler circuit. The first simplified version is shown on Figure 8.

DECODER WITH PULSE-EDGE BLANKING CIRCUIT

52. The operation of this circuit is entirely analogous to the one previously described, except for the new technique developed for edge-effect suppression.

53. In the previously described circuit, the edge effects were eliminated by applying to the suppressor grid of the coincidence tube (VT 4, Figure 3) a new signal derived from the input pulse, narrower than the original pulse by its rise and fall time, and corresponding in time to the center of the original pulse. Here, the effect of the edges of the pulse will be nullified by generating negative pips in time correspondence with the leading and trailing edges of the signal pulses. These pips will be used to prevent an output from the coincidence tube VT 6 during the rise and fall times of the signal pulses.

**Division 14, NDRC Report No. 565 of October 1945; Final Report of Preparation of High Back Voltage Germanium Rectifiers by J. H. Scaff and H. C. Theurer.

††The spike suppression circuit is a delay line pulse width discriminator circuit, consisting of a short delay line (equal to maximum pulse width to be suppressed) and a coincidence mixer. NRL ltr. C-S67/89Mk 5(1354HMS), C-1350-3/47.

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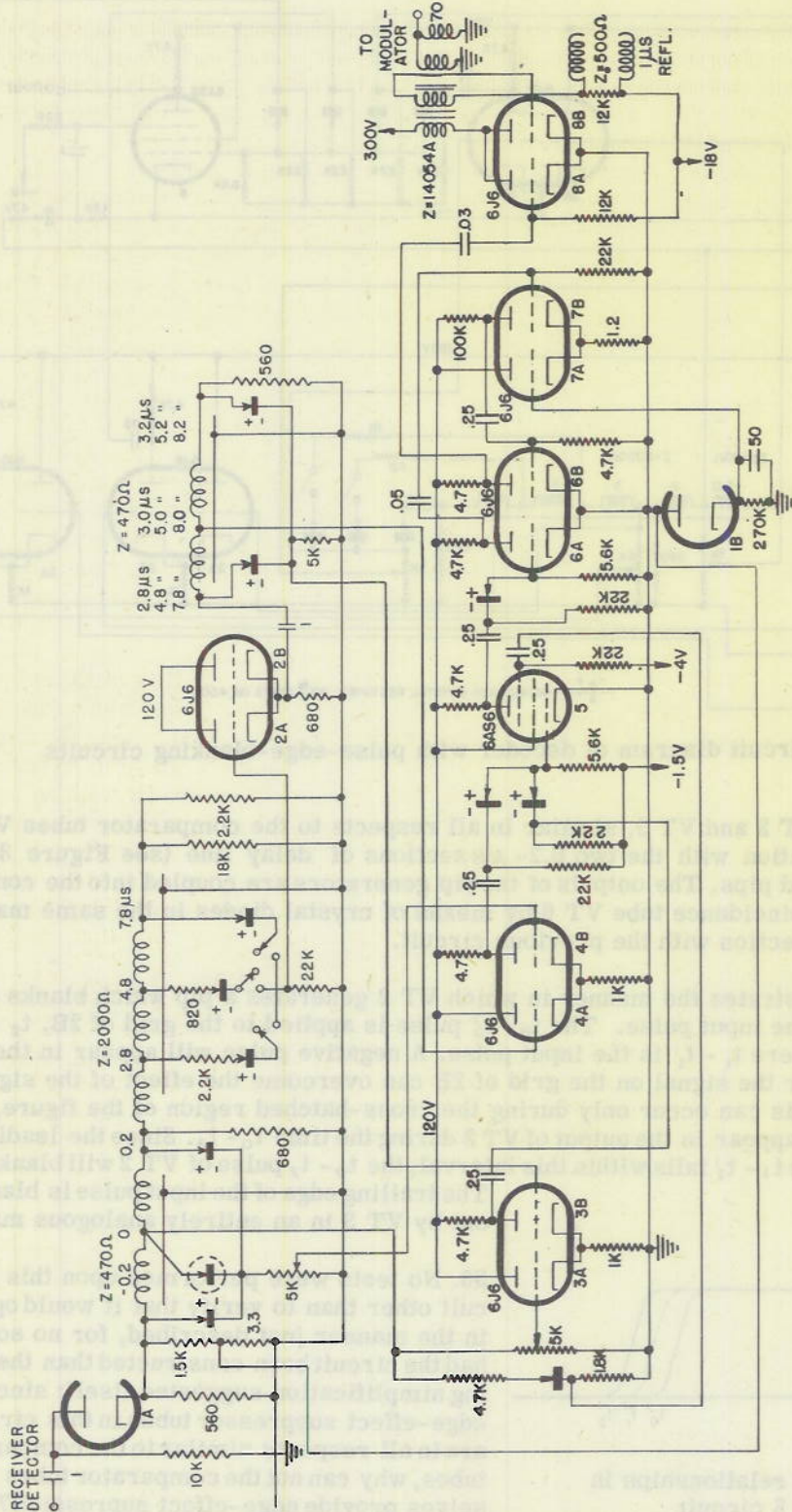


Figure 10. Circuit diagram of decoder with comparator-tube edge-effect elimination

DECODER WITH COMPARATOR-TUBE EDGE-EFFECT ELIMINATION

57. The answer to this question is contained in Figure 10. Essentially, the complete decoder, providing both echo and spike suppression, has been reduced to three tubes--two comparators and a single coincidence tube.

58. The analysis of the operation of this new decoder will be more complex than previous analyses, because of the multiplicity of functions performed by the comparator tubes. However, the discussion can be simplified by stating that the comparators perform in precisely the same manner as described in connection with Figure 3 and, therefore, the discussion may be confined to those circuit modifications which have enabled the comparators to perform these new functions.

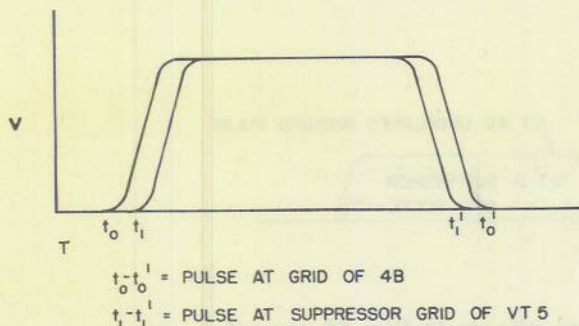


Figure 11. Time relationships of Figure 10 circuit

59. By means of diode mixing, the signals at the $-0.2 - \mu s$ position and the $0.2 - \mu s$ position of the delay line have been combined in a common load resistor. The time relationship of this signal to the signal derived from the 0 position of the delay line (the signal applied to the suppressor grid of the coincidence tube) is shown on Figure 11.

60. Consider the operation of the comparator VT 4 for the cases shown in Figure 5, remembering that whenever the ratio of the signal on the VT 4B grid to the signal on the VT 4A grid exceeds a predetermined value, the output of VT 4B will be negative. VT 4 discriminates against the pulse pairs wherein the first pulse is of a lesser amplitude than the second. Limiting ourselves, for the moment, to the single comparator VT 4, three waveforms must be considered simultaneously in order to determine the output of the coincidence tube. They are: the signal on the VT 4A grid, that on the VT 4B grid (these two determine the signal on the control grid of the mixer tube), and that on the suppressor grid of VT 5.

61. The case of perfect coincidence is shown in Figure 12 (A). The use of the wide pulse on the VT 4B grid has prevented the time coincidence of the edges of the delayed and undelayed pulses. The output of VT 4B will be a negative pulse wider than the signal on the VT 5 suppressor grid. Thus, there is no output from VT 5 (by an output from VT 5, we mean a pulse of negative polarity) even during the rise and fall time of the VT 5 signals.

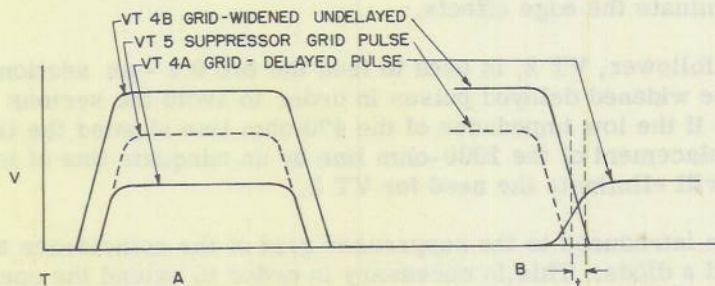


Figure 12. Elimination of edge effects in Fig. 10 circuit

62. The case of overlapping edges is shown in Figure 12 (B). Here the effect of the wide pulse on the VT 4B grid is to cause the interval "t", during which the information from the comparator regarding the amplitudes of the pulses is incorrect, to occur when there is no longer any signal present on the VT 5 suppressor grid.

63. Figure 13 shows a case where the wide pulse on the VT 4B grid does not provide adequate protection, for not until the point t_1 has been reached does the VT 4B output become negative. But, beginning at the time t_0 , there is signal voltage present upon the VT 5 suppressor grid. Thus, VT 5 may produce a false output during the time interval $t_0 - t_1$.

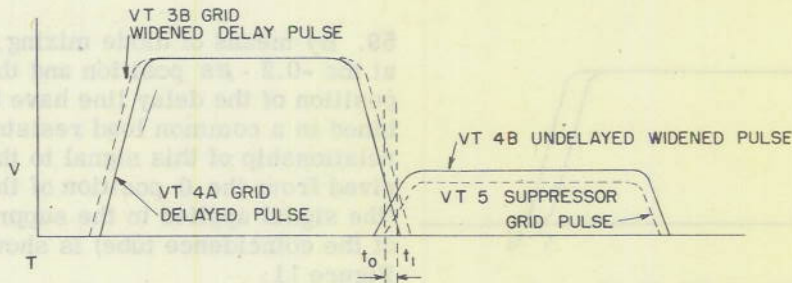


Figure 13. Elimination of edge effects in Fig. 10 circuit

64. Let us examine, now, the functioning of the comparator VT 3 for the case shown on Figure 13. If the VT 4A grid pulse appears upon the VT 3B grid, and the VT 5 suppressor-grid pulse appears upon the VT 3A grid, the output of VT 3B will cease to be negative at the time t_0 (VT 3 is the comparator which rejects pulse pairs wherein the first pulse has the greater amplitude). The interval during which VT 5 is unprotected is $t_0 - t_1$. If, instead of the VT 4A pulse, the pulse indicated by the dashed line (corresponding to a widened delayed pulse) is substituted for it, the output of VT 3B will be negative until the time t_1 , and, therefore, the possibility of a false output from VT 5 will be eliminated. The two $0.2 - \mu s$ sections of 470-ohm line at the end of the body of the delay line provide the comparator VT 3 with widened delayed pulses.

65. An analysis of the circuit operation as regards specific configurations of the pulses, follows in a manner similar to the above discussions. To summarize briefly, the use of wide pulses in the manner just described has enabled the comparators to supply to the coincidence tube information concerning the relative amplitudes of the pulses for the entire duration of a signal on the suppressor grid of the coincidence tube, and thereby to eliminate the edge effects.

66. A cathode follower, VT 2, is used to feed the two $0.2 - \mu s$ sections of 470-ohm line which form the widened delayed pulses in order to avoid the serious mismatch which would occur if the low impedance of the 470-ohm line shunted the taps of the 2000-ohm line. The replacement of the 2000-ohm line by an adequate line of lower impedance (about 500 ohms) will eliminate the need for VT 2.

67. Signals are introduced to the suppressor grid of the coincidence tube through a voltage divider and a diode. This is necessary in order to extend the operation of the circuit to the minimum voltage level of the anticipated signals. Since a 0.5-volt signal at the input will result in a signal of only approximately 0.1 v at the control grid of the

coincidence tube, the level of signal at the suppressor grid must be reduced to this level if the outputs of the comparator tubes are to exercise control over the coincidence tube. At these low signal levels, the nonlinearity of the diodes becomes important, and the diode in the suppressor-grid circuit of the coincidence tube enables the signal on the suppressor grid to vary in a similar manner to those on the control grid.

68. An amplifier and a blocking oscillator (VT 6 and VT 8) were included after the coincidence tube to simulate actual decoder operation. When the circuit was tested, a pair of pulses were said to have been decoded if the blocking oscillator triggered.

69. VT 1B and VT 7 formed an automatic-gain-control circuit which determined the level of signal, relative to a given amplitude of signal at the decoder input, required to trigger the blocking oscillator. The circuit was adjusted to eliminate signals of about one-tenth the amplitude of those appearing at the input.

70. This circuit was inserted to eliminate the possibility that wiggles generated by the delay line would trigger the blocking oscillator, but a more careful investigation of the effect (after the data on the circuit had been gathered) revealed that at high signal levels (about 20 v) the triggering was caused by small positive signals on the control grid of the coincidence tube. The presence of positive signals indicated faulty diodes, and when the diodes were replaced, this defect was eliminated.

71. At high signal levels (20 v and above), however, the blocking oscillator was triggered by the appearance at the plate of VT 5 of a small differentiated replica of the pulses on the suppressor and control grids. The larger of the spikes corresponded to the control grid signal. Even when VT 5 was removed from the circuit, spikes appeared at the plate. Further research on this point is required to clarify the situation. It is believed that the difficulty can be overcome and that VT 1B and VT 7 can be eliminated.

PERFORMANCE OF THE FIGURE 10 DECODER

72. The laboratory setup for obtaining data on the operation of the decoder is shown in the block diagram of Figure 14. A CRG Synchroscope provides synchronizing pulses for the variable coder and the oscilloscope, TS-239 XN-1/UP. Its 1- μ s and 0.1- μ s marker pips provide a convenient method for measuring the spacing of the pulses.

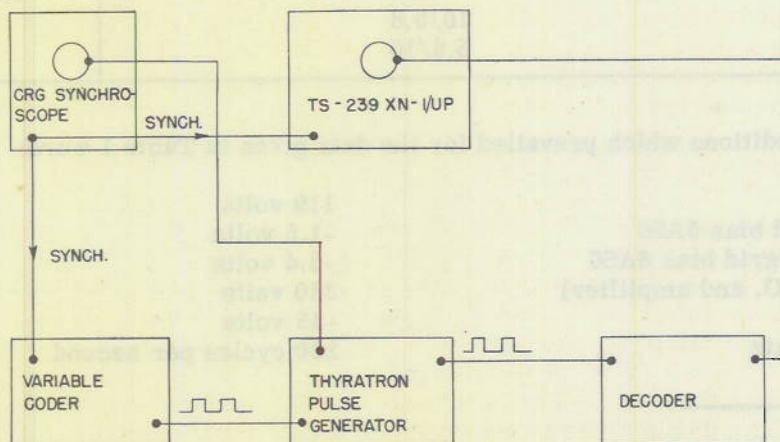


Figure 14. Block diagram of laboratory test equipment

The TS-239 XN-1/UP oscilloscope, used for the observation of the decoder waveforms and the measurement of the pulse amplitudes, has a self-contained, vertical-deflection voltage calibrator, and sufficiently good signal amplifiers to permit pulses with amplitudes of the order of 0.1 v to be viewed without appreciable distortion. The variable coder provided two pulses which could be varied continuously in spacing from $2\mu\text{s}$ to $11\mu\text{s}$. The test pulses were generated by thyratron pulse generators^{††} which produce two flat-topped pulses, individually variable in amplitude from 0 to 70 volts, with rise and fall times of about $0.15\mu\text{s}$.

73. The decoder was adjusted as follows: with 10-volt signals at the input, the comparators were set to discriminate against a properly coded pulse pair whose amplitudes differed by 4 db or more. The decoder was then briefly checked over its entire range of operation to ascertain whether precise measurements were to be taken. If the decoder operated correctly over its entire range, its operation on the $5\text{-}\mu\text{s}$ code was checked in detail to determine the way in which the decoding range and ratio of pulse amplitudes varied with the signal level.

Table 1

Signal Level volts	Amplitude Ratio	Decoding Range (μs)
0.55	1	4.69 - 5.50
1	1	4.53 - 5.68
1	10/5.0	0
1	6.2/10	0
3	1	4.50 - 5.68
3	10/4.0	0
3	5.8/10	0
10	1	4.47 - 5.66
10	10/6.0	0
10	6.2/10	0
30	1	4.45 - 5.60
30	10/6.5	0
30	6.0/10	0
50	1	4.45 - 5.60
50	10/5.6	0
50	5.6/10	0

74. The conditions which prevailed for the data given in Table 1 were:

B+	119 volts
Control-grid bias 6AS6	-1.5 volts
Suppressor-grid bias 6AS6	-3.4 volts
B+ VT 8 (B.O. and amplifier)	330 volts
VT 8 bias	-18 volts
repetition rate	230 cycles per second

^{††} A description of a pulse generator of this type is contained in CRG Technical Memorandum No. 92 of 16 October 1945.

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The bias voltages were obtained from a regulated power supply. The figures in the ratio column are relative; that is, the 10 represents the voltage amplitude of the larger signal, which is the value indicated in the signal level column. The smaller signal is indicated by the smaller number, and its actual value is given by: $\frac{\text{signal level} \times \text{the number}}{10}$. The numbers in the ratio column have a precision of ± 0.2 . The numerator refers to the first pulse and the denominator to the second.

75. In order to determine the effect on the range of decoding of pulse pairs within the limiting ratios but different from unity, data was taken for pulse pairs with ratios of 10/8 and 8/10 over the entire 40 db range of operation. For these ratios the range of decoding never differed by more than $0.05 \mu s$ from that obtained for the unity ratio, or by little more than the precision of the measurement.

76. The parameter believed to be most influential in determining the stability of the decoder operating range is the B+ voltage of the comparators and the coincidence tube. The data presented in Table 2 indicates the variation of the decoder's operating range as a function of B+ voltage when the other parameters are held constant at the values given for Table 1.

Table 2

B+ voltage	Signal Level volts	Amplitude Ratio	Decoding Range (μs)
109	min. 0.7	1	
	10	1	4.48 - 5.67
	10	10/6.0	0
	10	6.2/10	0
	50	1	4.45 - 5.60
	50	10/5.6	0
	50	6.0/10	0
	119	min. 0.6	1
10		1	4.47 - 5.68
10		10/6.2	0
10		6.2/10	0
50		1	4.45 - 5.60
50		10/5.6	0
50		5.6/10	0
130		min. 0.6	1
	10	1	4.48 - 5.67
	10	10/6.0	0
	10	6.2/10	0
	50	1	4.45 - 5.63
	50	10/6.0	0
	50	6.0/10	0

77. The operation of the decoder was then checked for varying repetition rates between 200 cps and 3000 cps at minimum signal and at an arbitrary signal (10 volts) with the circuit voltages held at the values given in connection with Table 1. Within this range of repetition rates (the thyatron pulse generator could not be triggered at a rate higher than 3000 cps), the operation of the decoder is not influenced by the repetition rate.

78. Although the highest signal level for which the decoder operation is tabulated is 50 v, the decoder operated satisfactorily at the maximum signal level available--70 v.

79. This decoder satisfies the imposed conditions, namely, short recovery time, non-paralysis in the presence of strong interfering signals, †† and suppression of echoes.

80. It was realized at this point that the decoder was vulnerable to spikes. Consider what occurs when a spike $0.2 \mu s$ wide at its base appears at the decoder input. At the time when there is a signal at the delay-line point "0", from which point the signal is introduced to the suppressor grid of the coincidence tube, there is no longer any signal present upon the grid of the comparator VT 4B, since it receives signals $0.2 \mu s$ earlier and $0.2 \mu s$ later than does point "0". Therefore, no control voltage appears at the control grid of the coincidence tube, and the decoder registers an output.

81. The decoder may be rendered insensitive to spikes by the following procedure. A diode is connected between the "0" tap and the common load resistor (diode encircled by broken line on Figure 10). Now, the comparator VT 4B will have a signal on its grid whenever one appears at the VT 5 suppressor grid.

82. With this modification in the circuit, the decoder was adjusted and tested as explained in paragraph 73. The decoder operation was then checked when the signals consisted of spikes and spike pairs. The spike signals were obtained by differentiation of the signal pulses and were roughly triangular in shape. They ranged in amplitude from 0 to 25 v, and in width at the base of the pulse from $0.25 \mu s$ at the low levels to $0.3 \mu s$ at the high levels. The decoder did not respond either to single spikes, or to spike pairs at any spacing, over the entire amplitude range (0 to 25 v), which indicates that it is invulnerable to spikes.

SYSTEM TOLERANCES

83. Although this study is meant to have general application, it is interesting to examine the system changes that would be required to accommodate this type of decoder in the Mark V IFF equipment. Assuming that the components which relate to pulse spacings and pulse width can be manufactured or adjusted so that they fall within preset tolerance limits, it is possible to calculate the minimum gate length (pulse widths required in the decoder) so that no matter in what combination these tolerances occur, the equipment will still operate. §§

84. Present Mark V IFF decoders require a gate length equal approximately to the pulse width. But all of the echo suppressing decoders described in this report employ some circuit which eliminates the effect of the rise and fall times of the signal pulses and thus effectively narrow the gate by that amount. The actual narrowing of the gate will depend upon both the slope of the signal pulse edges and the amplitude-discrimination setting. Therefore, in order that this decoder satisfy the tolerance requirements, a wider pulse must be employed, so that the gate length after elimination of the pulse edges equals approximately the present Mark V decoder gate length.

†† In par. 41 of this report, the only known case wherein the presence of a strong interfering signal would cause the decoder to fail to respond, is discussed.

§§ CRG Report No. 17 of January 6, 1945: The Development of Decoders for the Mark V IFF System by G. B. Parkinson; pp. 9 - 12.

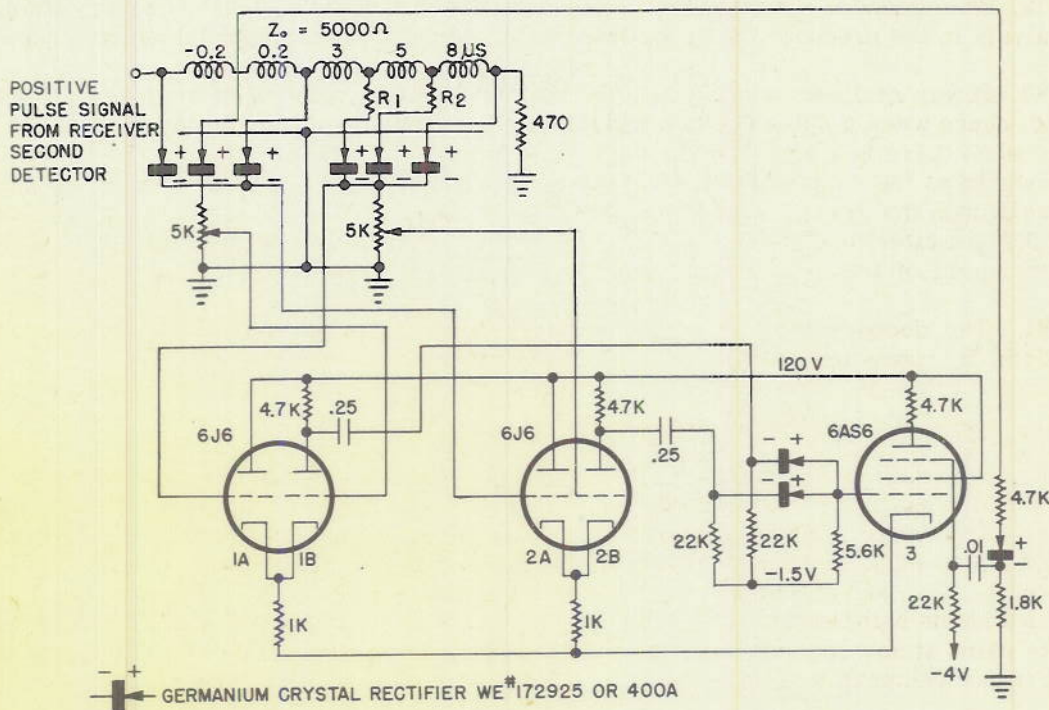


Figure 15. Proposed decoder

PROPOSED DECODER

85. On Figure 15 is shown the basic decoder circuit which is capable of analyzing a pulse sequence as to amplitude and spacing, and which is, at the same time, invulnerable to spikes. This circuit is simpler than that of Figure 10 because of the elimination of widening of the delayed pulses. This results, effectively, in poorer amplitude discrimination for certain pulse configurations (see Figure 13). However, poorer discrimination for certain pulse configurations is not significant, since the circuit will still exercise sufficient discrimination to eliminate the majority of echoes, and the particular cases in which it will allow the transponder to act falsely will be rare.

CONCLUSIONS

86. The most effective approach to the solution of the echo-suppression problem has been through the design of a new decoder. A decoder, such as shown on Figure 15, is capable of providing both spike and echo suppression in such a manner as not to impart to the decoder a recovery time.

87. The circuits described in this report successfully solve the problem of pulse-amplitude comparison over a 40 db range of amplitude.

88. The technique of diode mixing of the signals at various delay-line taps, with the consequent economy of mixer tubes, is applicable to the decoders now employed in the Mark V IFF system.

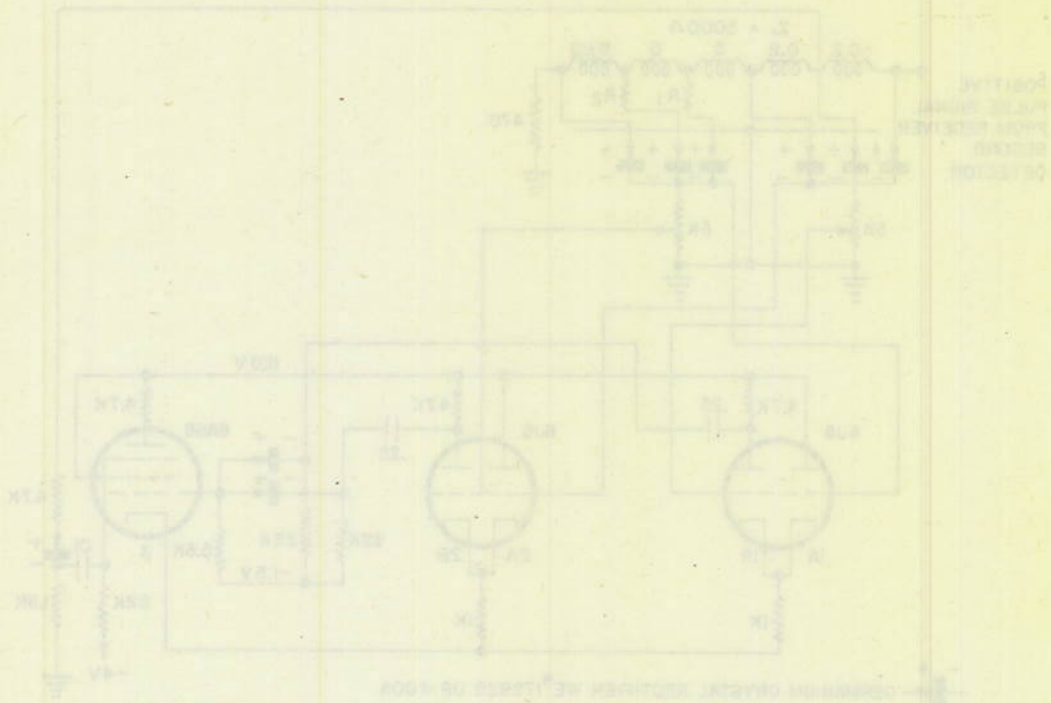


FIGURE 10. Proposed Decoder

PROPOSED DECODER

56. The most effective approach in the solution of the audio-degeneration problem has been through the design of a new decoder. A decoder, such as shown in Figure 10, is capable of eliminating both audio and video degeneration at such a point as will be important in the receiver's recovery time.

57. The circuit described in this report not only solves the problem of audio amplification over a 40 db range of signals.

58. The technique of block coding of the signals at various delay-line taps with the consequent recovery of video data, as applicable in the decoder now equipped in the Mark V TV system.

CONCLUSIONS

59. On Figure 10 is shown the basic decoder circuit which is capable of analyzing a pulse waveform as to amplitude and spacing, and which is, at the same time, insensitive to phase. This circuit is simpler than that of Figure 10 because of the elimination of a video detector. This results effectively in better amplitude discrimination for certain pulse configurations (see Figure 10). However, poorer discrimination for certain pulse configurations is not indicated, since the circuit will still exercise sufficient discrimination to eliminate the majority of echoes, and the particular cases in which it will allow the transistor to not identify will be rare.